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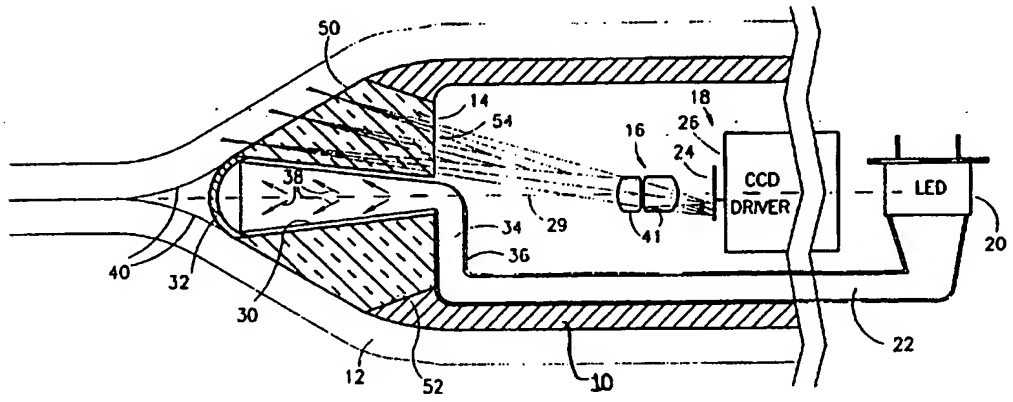
(54) Optical system for imaging inner walls of flexible tubes

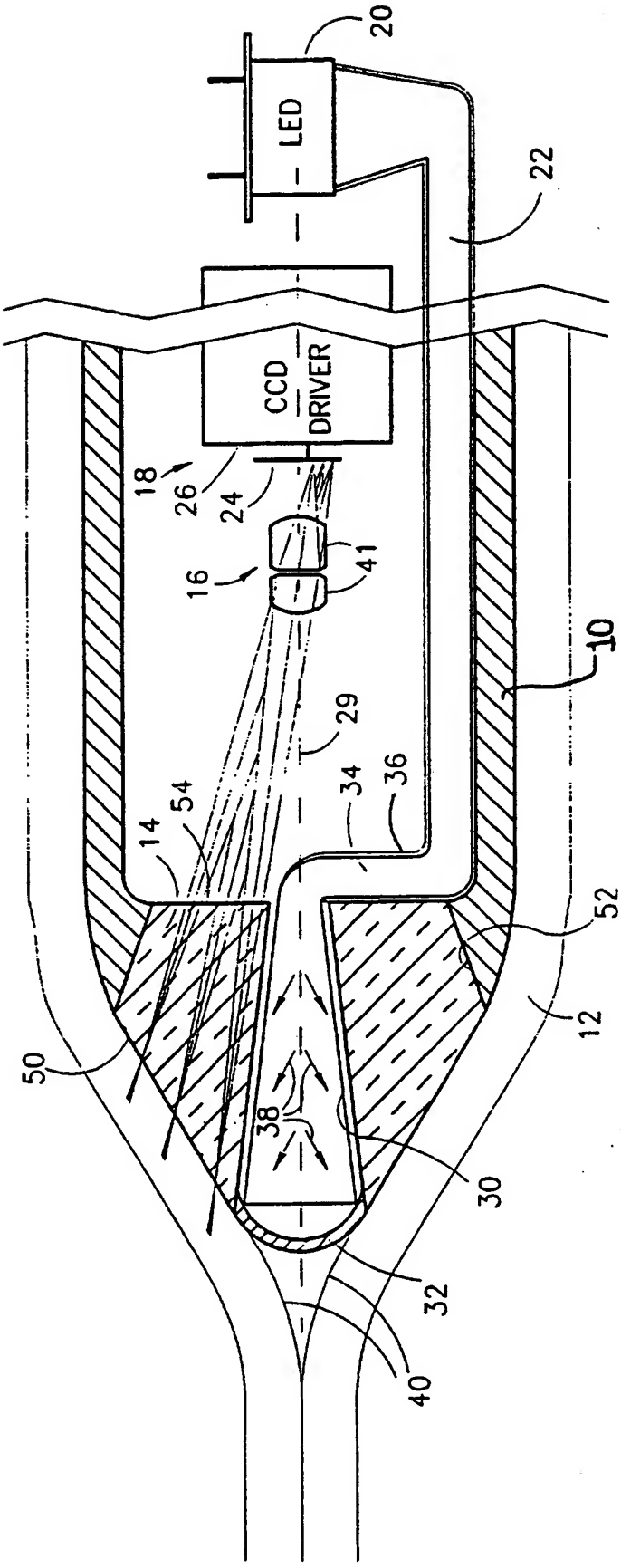
(57) An optical system has an optional relay lens 16 and an optical element 14 which is formed substantially in the form of a rotated trapezoid. The optical element 14 abuts the inner walls 40 of a flexible tube 12 and forms a conical object surface. The top of the optical element 14 enters the flexible tube 12 first, so that, if the tube collapses, the optical element serves to open the tube. The optical element 14 compensates for the variable distance object plane, and the relay lens 16 images the compensated object onto a detector plane 24. The optical element has a borehole 30 and the optical system also includes a light source 20 and a lightguide 22 extending from the light source through the borehole. Cap 32 may be a lens in which case illumination comes from the side of housing 10.

FIG. 1



GB 2291980 A

FIG. 1


LED
20
22
CCD
DRIVER
18
26
24
16
41
10
29
34
36
54
14
52
12
50
38
30
32
40

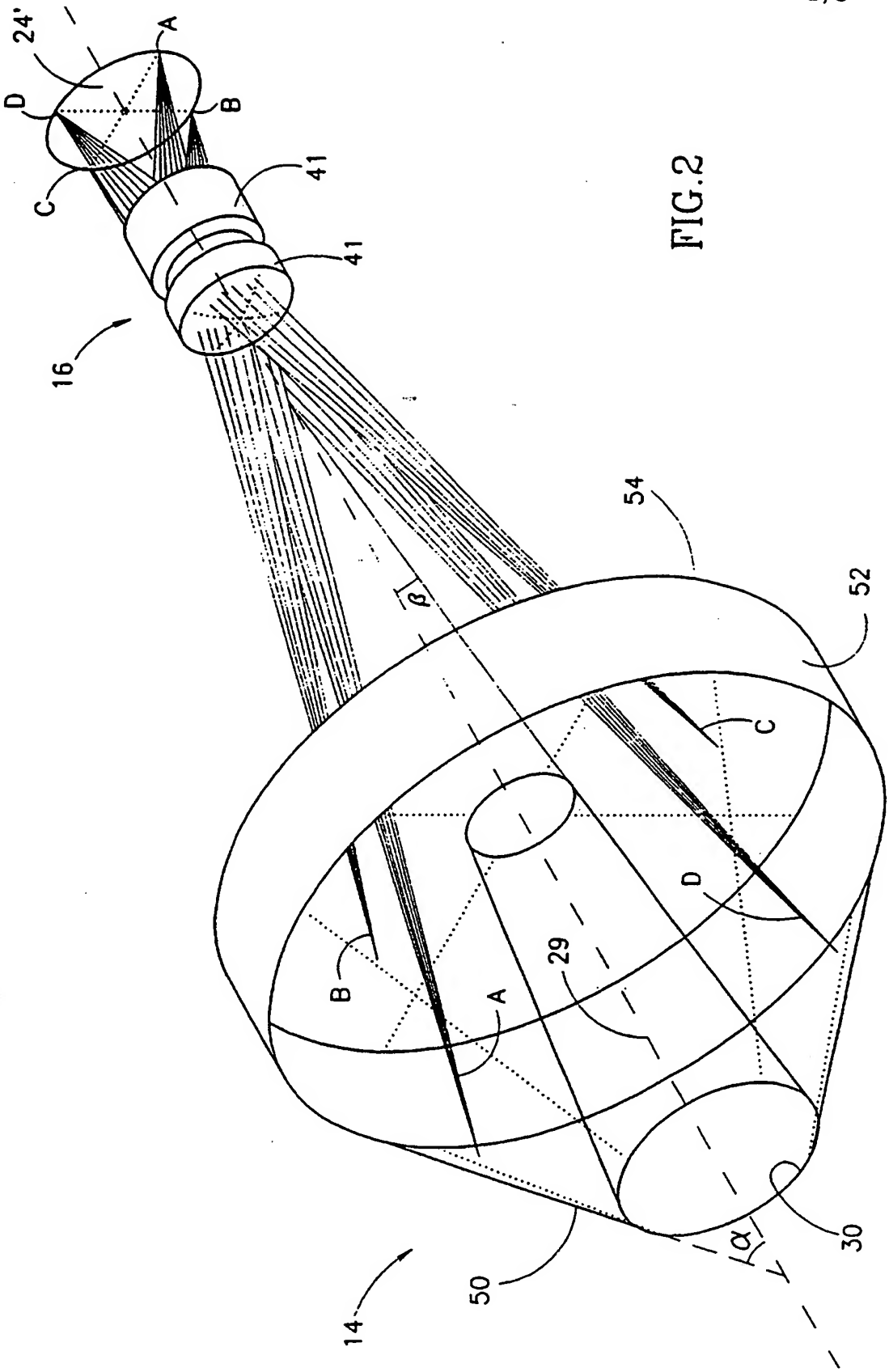


FIG.2

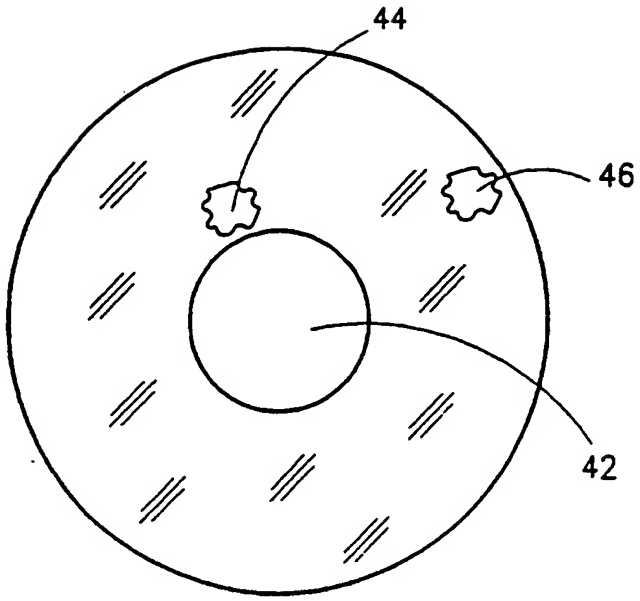


FIG.3

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AN OPTICAL SYSTEM FOR FLEXIBLE TUBES

The present invention relates to optical systems for imaging the inner walls of a flexible tube.

It is often desired to peer into the inner depths of a tube, such as a pipe, blood vessels and the intestines. For this purpose, endoscopes were invented. Endoscopes include a flexible tube which can move through the tube and an optical system at the far end of the tube for imaging the inner depths of the tube. Typically, the endoscopic optical system looks directly ahead of the tube and has a field of view in front of the tube. Thus, the optical system images both the inner walls of the tube and the contents within the tube, provided that the objects fall within the depth of field of the optics.

Such an optical system works well with rigid or semi-rigid tubes. However, it cannot image the inner walls of a flexible tube, such as the small intestines or a collapsible pipe, since the location of the walls vis-a-vis the optical system is not fixed and the objects to be imaged are located very close to the lens. Specifically, the problem is that the available field of view is limited to the immediate vicinity of the front lens and the object distance for the lens is not well defined.

The present invention seeks to provide an optical system for imaging the inner walls of flexible tubes.

According to a first aspect of the present invention there is provided an optical system for imaging the inner walls of a flexible tube comprising an optical element arranged to contact the inner walls of the flexible tube, wherein said optical element has angled outer sides forming a substantially conical object surface.

The present invention also extends to an optical system having an axicon element, formed at least from a rotated trapezoid, abutting the inner walls of a flexible tube. The axicon element has an object plane which is at a variable distance to an image plane which is parallel to the base of the axicon element. In other words, the axicon element forms a conical object surface.

Since the top of the axicon element enters the flexible tube first, if the tube has collapsed, the axicon element serves to open the tube up.

The optical system additionally includes a relay lens. The axicon element compensates for the variable distance object plane and the relay lens images the compensated object onto a detector plane.

In an embodiment of the present invention, the axicon element has a borehole and the optical system also includes a light source and a lightguide extending from the light source through the borehole. The lightguide provides light throughout the borehole. It can have a coating everywhere but within the borehole.

According to a further aspect of the present invention there is provided a method of imaging a flexible tube. The method comprises the steps of forcing an optical element, which has a conical outer surface, against inner walls of the tube thereby to create a conical object on at least part of the conical outer surface, and relaying a planar compensated version of the conical object to a detector element.

Embodiments of the present invention will hereinafter be described, by way of example, with reference to the

accompanying drawings, in which:

Figure 1 is a side view illustration of an optical system for viewing the inner walls of flexible tubes in accordance with the present invention;

Figure 2 is an isometric illustration of the optical paths of four light beams through the optical system of Figure 1; and

Figure 3 is a schematic illustration of the image received at the detector plane, useful in understanding the operation of the optical system of Figure 1.

Reference is now made to Figures 1 to 3 which illustrate an optical system of the present invention and how it works. The optical system is typically located at one end of a tubular housing 10 and is utilized to move through a flexible tube 12.

The optical system comprises an axicon optical element 14, which provides the angled front end, a relay lens unit 16, an image detector 18, a light source 20 and a lightguide 22. The image detector 18 is typically centered around an axis of symmetry 29 which also serves as the optical axis of the optical system. The image detector 18 typically comprises a detector 24, such as a charge coupled device (CCD), and its associated driver 26.

The axicon element 14 is the result of a rotation of a trapezoid around the axis 29. The outer sides of axicon element 14 are angled and, since axicon element 14 is the first element of the optical system to enter the flexible tube 12, axicon element 14 serves to "open up" the collapsed flexible tube 12 through which the optical system moves. As a result, the inner walls, labelled 40, of the flexible tube 12 are pressed against the outer sides of axicon element 14.

The axicon element 14 typically has a borehole 30 in the center thereof which is covered by a rounded cap 32. Axicon borehole 30 can be cylindrical or angled, as shown in the Figures.

The lightguide 22 typically guides light from the light source 20, such as a light emitting diode (LED), to within the borehole 30. Lightguide 22 is typically a fiberoptic lightguide formed of a glass fiber 34 coated with a covering 36 which is operative to maintain the light within the lightguide 22. As shown, the portion of the lightguide 22 within borehole 30 is not clad with covering 36 and therefore, can provide light to the axicon element 14. Arrows 38 indicate the directions taken by the light emitted by the lightguide 22.

The lightguide 22 provides light to illuminate the inner walls 40 of flexible tube 12 which press against the axicon element 14 as the optical system of the present invention passes by. Thus, the object to be detected is present on the surface of the axicon element 14.

The objects to be detected are the inner walls 40 of a flexible tube. Due to the angled shape of the axicon element 14, the inner walls 40 are forced against the outer surface of the axicon element 14, thereby ensuring the creation of an object whose distances to the detector 24 are well defined. However, the resultant object is tilted with respect to the optical axis 29.

As is known in the art, tilted objects form images only on tilted flat detectors placed at an angle to the optical axis. This problem is known in the art as the "Scheimpflug Condition". It is discussed on pages 812 - 813 of the Manual of Photogrammetry, Vol. 1, Third Edition, American Society of Photogrammetry, 1966, which book is

incorporated herein by reference. Specifically, the Scheimpflug Condition requires that the tilted object plane, the principal lens plane and the image plane must concur at a point. When imaged with conventional lenses, conical objects form conical image planes which, in turn, produce distorted and defocussed images on a flat detector.

In addition to creating the shape of the object to be detected, the axicon element 14 compensates for the conical shape of the object. This compensation is provided by the fact that the axicon element 14 is a "wedge" rather than just a conical surface. The wedge ensures that beams originating from different parts of the tilted object follow different length optical paths, the optical lengths being designed to generally compensate for the Scheimpflug Condition. Thus, the axicon element 14 produces a perpendicular object and enables the relay lens unit 16 to form an image on the detector 24 when detector 24 is perpendicular to the optical axis 29.

The relay lens unit 16 is a wide angle relay lens unit which reduces the size of the perpendicular object produced by the axicon element 14. It also serves to reduce the optical aberrations of the optical system to a minimum. As shown in Figures 1 and 2, the relay lens unit 16 comprises two lenses 41.

The axicon element 14 images a torus-shaped image onto detector 24. An example of such a torus-shaped detected image is illustrated in Figure 3. The torus-shaped image has a hole 42 due to the presence of borehole 30.

In the example of Figure 3, the blob labelled 44 is extremely close to the borehole 30 and the blob labelled 46 is currently close to the outer edge of element 14. As the optical system moves further into the flexible tube 12,

blob 44 moves radially towards the outer edge of the image of Figure 3.

Axicon element 14 is typically formed of any suitable translucent material, such as glass or plastic. It has an axicon outer surface 50 (Figure 2) having an angle α with the axis of symmetry 29, sides 52 and an inner surface 54.

The smaller the angle α is, the easier it is for the inner walls 40 to move along axicon element 14. However, if the angle α is too small, an element 14 may not be able to compensate for the Scheimpflug Condition.

Figure 2 provides a ray tracing for four beams A, B, C and D. It can be seen from the points A, B, C and D labelled on the detector plane 24', that the tilted object of the outer surface 50 of axicon element 14 is imaged on the detector plane 24'. It can further be seen that axicon element 14 does not focus the image.

The following are the parameters of the optical system of the present invention for an exemplary embodiment:

Outer diameter of housing tube 10: 8mm
angle α of axicon outer surface 50: 25 - 35°
diameter of detector 24: 2.5 - 6.0mm
effective focal length of optical system: 2mm
F/# of element 14, from image side: F/2.3
Magnification: Mx1/4
Annular field of view: between 12° and 20°
Size of image on detector 24:
  outer diameter: 1.8mm
  inner diameter: 0.6mm

In an alternative embodiment of the present invention, cap 32 is formed of a lens thereby allowing imaging of the center of the flexible tube. However, this requires that

the illumination come, not through the borehole, but from the side of the housing 10.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Modifications and variations may be made to the described embodiments within the scope of the appended claims.

CLAIMS

1. An optical system for imaging the inner walls of a flexible tube comprising an optical element arranged to contact the inner walls of the flexible tube, wherein said optical element has angled outer sides forming a substantially conical object surface.

2. An optical system for imaging the inner walls of a flexible tube, the optical system comprising:

an axicon optical element having a conical outer surface which, when said conical outer surface is in contact with said inner walls, creates a conical object on said conical outer surface, for compensating for the conical shape of said conical object;

an image detector; and

a relay unit which relays said compensated object to said image detector.

3. An optical system as claimed in claim 2, wherein said optical element is located before said relay unit and said image detector thereby to enter said flexible tube first and to open up said flexible tube if it has collapsed.

4. An optical system as claimed in claim 2 or claim 3, wherein said axicon optical element has an axis of symmetry and a borehole centered around said axis of symmetry.

5. An optical system as claimed in any preceding claim, further comprising a light source and a lightguide extending from said light source to said optical element.

6. An optical system as claimed in claim 5, wherein said optical element has a borehole, and said lightguide extends from said light source to within said borehole, said lightguide having a coating everywhere but within said

borehole.

7. A method of imaging a flexible tube, the method comprising the steps of:

forcing an optical element having a conical outer surface, against inner walls of said tube thereby to create a conical object on at least part of said conical outer surface; and

relaying a compensated version of said conical object to a detector element.

8. An optical system for imaging a flexible tube substantially as hereinbefore described with reference to the accompanying drawings.

9. A method of imaging a flexible tube substantially as hereinbefore described with reference to the accompanying drawings.

Patents Act 1977 10 Examiner's report to the Comptroller under Section 17 (The Search report)	Application number GB 9514496.0
Relevant Technical Fields (i) UK Cl (Ed.N) G2J (JB7R4); H4F (FAAA, FCC) (ii) Int Cl (Ed.6) G02B; A61B	Search Examiner MR C ROSS Date of completion of Search 21 SEPTEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1-9

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Y:	Document indicating lack of inventive step if combined with one or more other documents of the same category.	E:	Patent document published on or after, but with priority date earlier than, the filing date of the present application.
A:	Document indicating technological background and/or state of the art.	&:	Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	WO 94/11040 A1	(KAALI) see especially page 8 line 20	1 at least
X	US 4149769	(WOLF)	1 at least

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